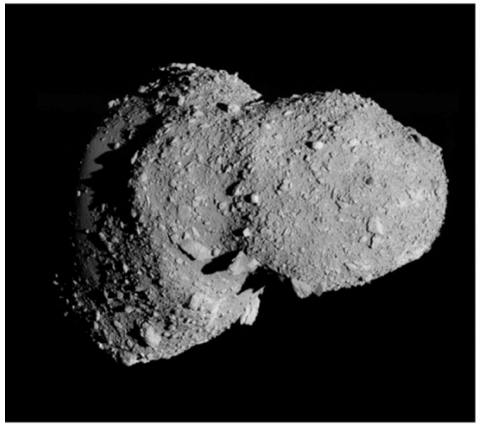
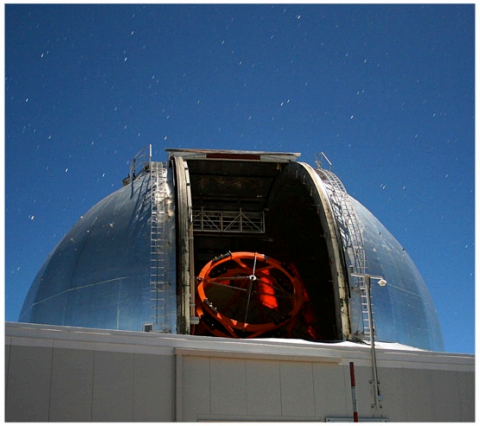
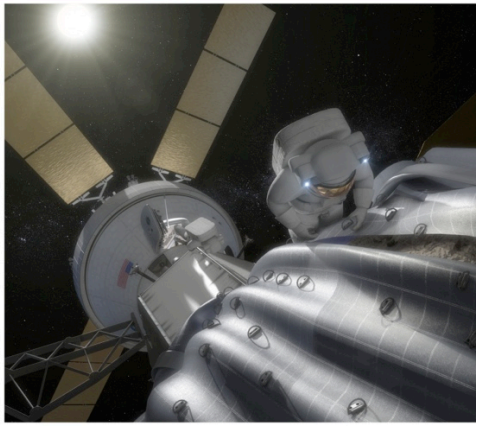
National Aeronautics and Space Administration

Asteroid Redirect Mission
Broad Agency Announcement

Chris Moore, Moderator
Panelists: Jasen Raboin, Heather Hinkel, Andrew Petro, Michael Barrett, Mark McDonald

March 26, 2014



NASA Asteroid Initiative Opportunities Forum • #AskNASA

BAA Objectives

- **Build upon RFI inputs and recommendations from the Asteroid Initiative Ideas Synthesis Workshop.**

- **Engage the external community in system concept studies, technology development activities, and studies of potential future partnership opportunities to support the goals of the Asteroid Initiative and reduce mission risk.**

- **Provide alternate system concepts for consideration during the ARM Mission Concept Review to be held in late 2014 or early 2015.**

BAA Topic Areas

- **Asteroid Capture Systems:** Asteroid capture system concepts including using deployable structures and autonomous robotic manipulators.

- **Rendezvous Sensors:** Rendezvous sensors that can be used for a wide range of mission applications including automated rendezvous and docking, and asteroid characterization and proximity operations.

- **Adapting Commercial Spacecraft for the Asteroid Redirect Vehicle:** Commercial spacecraft design, manufacture, and test capabilities that could be adapted for development of the Asteroid Redirect Vehicle.

- **Studies of Potential Future Partnership Opportunities for Secondary Payloads**: Studies of potential future partnership opportunities for secondary payloads on either the Asteroid Redirect Vehicle or the Space Launch System (SLS).

- **Studies of Potential Future Partnership Opportunities for the Asteroid Redirect Crewed Mission:** Studies of potential future partnership opportunities for the Asteroid Redirect Crewed Mission in areas such as advancing science and in-situ resource utilization, enabling commercial activities, and enhancing U.S. exploration activities in cis-lunar space.

Award Information

Solicitation Topic	Total Available Funding	Anticipated Number of Awards	Maximum Individual Award
Asteroid Capture Systems	$2M	4-5	$500,000
Rendezvous Sensors	$1.8M	4-6	$450,000
Adapting Commercial Spacecraft for the Asteroid Redirect Vehicle	$1.8M	4-6	$450,000
Studies of Potential Future Partnership Opportunities for Secondary Payloads	$0.2M	4	$50,000
Studies of Potential Future Partnership Opportunities for the Asteroid Redirect Crewed Mission	$0.2M	4	$50,000

Notices of Intent

- **NASA strongly encourages, but does not require, the submission of a Notice of Intent (NOI) to propose by all prospective offerors.**

- **The NOI should contain the following information:**
  - Name, address, telephone number, email address, and institutional affiliation of the offeror.
  - The solicitation topic in which you intend to propose.

- **The NOI should be submitted by email to the Point of Contact listed in the BAA.**

Proposals

- **Proposal Content:**
  - Title Page
  - Section I: Executive Summary
  - Section II: System Concept
  - Section III: Technical Approach
  - Section IV: Capabilities
  - Section V: Data Rights
  - Section VI: Price Proposal
  - Section VII: Draft Statement-of-Work

- **Proposals are limited to 20 pages (page limits for each section are specified in the BAA).**

- **Proposals should be submitted by email in Adobe PDF format to the Point of Contact listed in the BAA.**

Evaluation Criteria

1. **Relevance –** The Government will evaluate the relevance of the proposal to the objectives of the Asteroid Initiative and the system requirements specified in the BAA.

2. **Technical Merit –** The Government will evaluate the quality, depth, and thoroughness of the proposed technical approach, and the organization's capabilities and the qualifications of key personnel.

3. **Cost –** The Government will evaluate the overall cost reasonableness of the firm fixed price to the Government, and the extent to which the offeror complied with the specified dollar limits in the BAA. The Government will evaluate the total direct labor hours by skill mix, travel, and subcontracts.

BAA Schedule

- Mar. 6 Synopsis Release
- Mar. 21 BAA Release
- Mar. 26 Asteroid Initiative Opportunities Forum
- Apr. 4 Notices of Intent due
- May 5 Proposals due (45 days)
- Jul. 1 Contracts Begin
- Oct. 31 Interim Reports to support Mission Concept Review
- Dec. 31 Contracts Complete (180 days period of performance)

Questions

- **Please address questions by email to:**

  Chris Moore

  NASA Headquarters

  Email: HQ-Asteroid-BAA@mail.nasa.gov

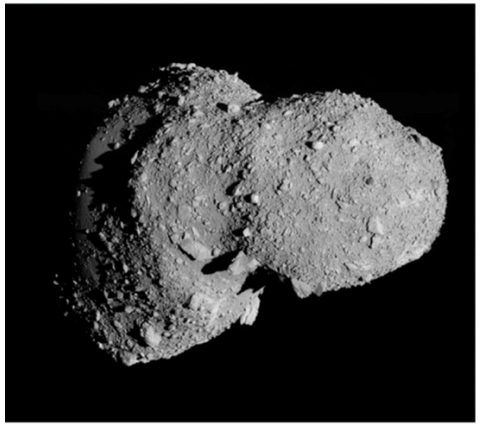
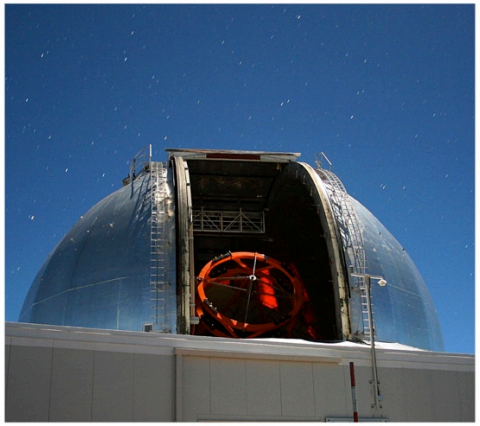
- **BAA website for reference information:**

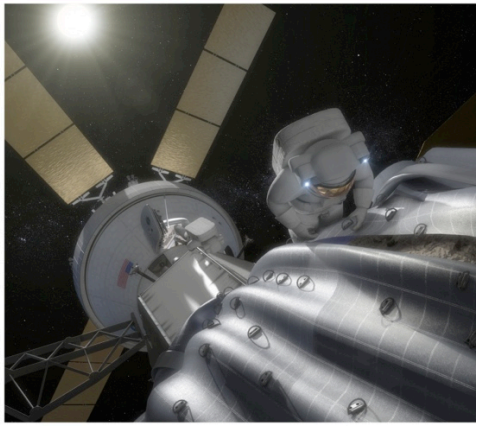
  http://www.nasa.gov/asteroidinitiative

National Aeronautics and Space Administration

Asteroid Capture Systems

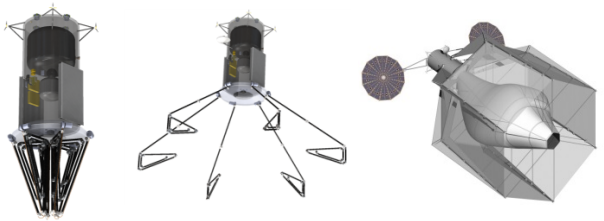
Jasen Raboin, JSC

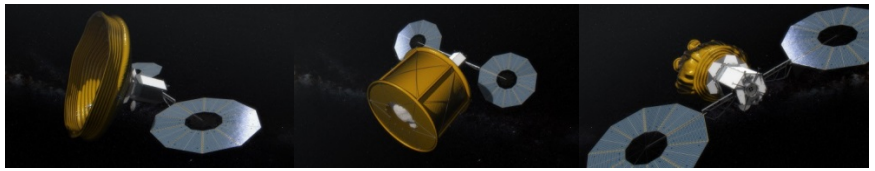


Events Leading Up to BAA Capture System Studies

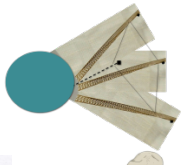
- **Asteroid Retrieval Feasibility Study**
  - Keck Institute for Space Studies (Sep 2011-Apr 2012)

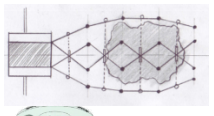


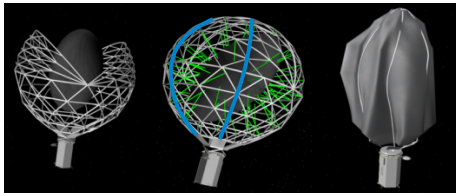
- **Reference Concept Development**
  - JPL (Jan 2013 - present)

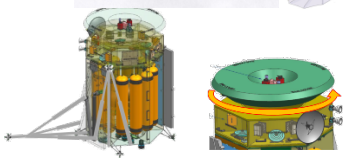


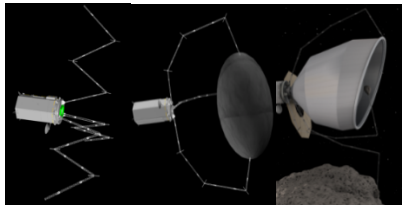
- **ARRM Capture System Trade Study**
  - NASA (Apr 2013)
  - 7 system concepts were reviewed
  - 11 sub-system concepts were reviewed
  - 2 concepts studied further



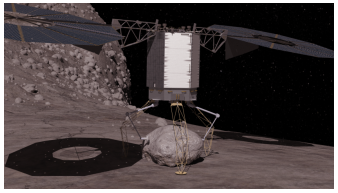




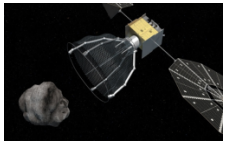


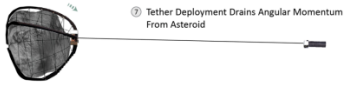


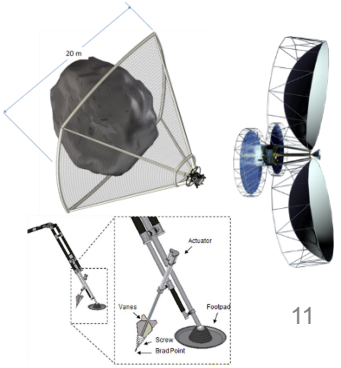
- **Alternate Concept Development**
  - LARC (Mar 2013 - present)



- **RFI request and Synthesis Workshop** (Nov 2013)
  - Industry, Academia and Government







BAA Capture System Studies

- **Objectives:**
  - **Build upon RFI inputs and recommendations from the Asteroid Initiative Ideas Synthesis Workshop.**
    - Conduct trade between deployable booms and inflatable beams with respect to the reference concept. Evaluate metrics such as; mass & complexity of system, launch packaging, de-tumble loads & dynamics, retraction/restraint of asteroid against spacecraft, etc.
    - In order to reduce the perceived risk of damaging large arrays/antennas on the spacecraft during the de-tumble event:
      - Conduct study to investigate cost effective ways to pre-condition (de-tumble) asteroid, prior to capture, to make it a more cooperative target. Consider tethers, as a means of momentum transfer, in the study.
      - Conduct study to investigate ways to make the spacecraft more robust against the de-tumble event. (retractable arrays, reconfigured arrays, higher performance rotational joint, deployable RCS booms)
  - **Provide alternate capture system concepts or on-ramp options for critical sub-systems for consideration during the ARM Mission Concept Review to be held in late 2014 or early 2015.**

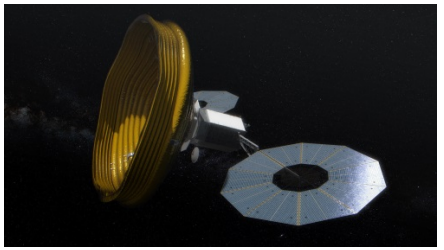
- **Eligible Participants:**
  - This solicitation topic is open to non-government U.S. institutions (companies, universities, non-profit organizations), and foreign institutions. NASA civil servants and JPL employees may not propose to this solicitation topic.

Small Asteroid Capture Option

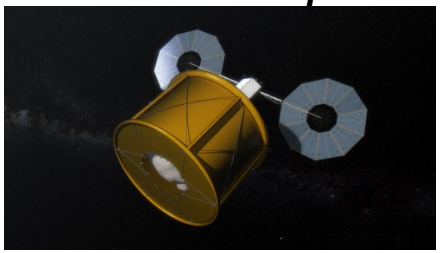
- One concept for the Asteroid Redirect Robotic Mission (ARRM) would use a cylindrical inflatable structure deployed from the robotic spacecraft to capture a small, slow spinning asteroid in a bag. Key technical challenges are capturing and de-spinning an asteroid that has uncertainty in its mass, shape, and spin rate, and containing asteroid material that may be a loose agglomeration of rocks and regolith (rubble pile).
- Since an asteroid capture system has never been developed before, it has low technology readiness, and consequently high risk. To mitigate risk, NASA is interested in developing alternate designs for packaging, deploying, closing, and restraining the asteroid inside the capture bag in parallel with the inflatable concept, and then down selecting to a single concept for flight system development. The asteroid material inside the bag needs to be accessible by EVA**.**
- NASA is particularly interested in, but not limited to:
  - Capture systems that use non-inflatable or hybrid methods to deploy a bag around an entire small near-Earth asteroid (NEA).
  - Materials compatible with long-duration deep space mission environments.
- Systems for acquiring an entire NEA shall be capable of capturing and de-spinning an asteroid with the following characteristics:
  - Asteroid size: 4 m < mean diameter < 10 m; maximum dimension is 13 m.
  - Asteroid mass: up to 1,000 metric tons
  - Asteroid rotation rate: up to 0.5 revolutions per minute.
  - Asteroid composition, internal structure, and physical integrity will likely be unknown until after rendezvous and capture.

The proposals shall provide a detailed technical approach for the design, analysis, fabrication, and laboratory testing of a proof-of-concept, subscale capture system. NASA may use the data resulting from this effort in the ARM Mission Concept Review (MCR), which is planned for late 2014 or early 2015.

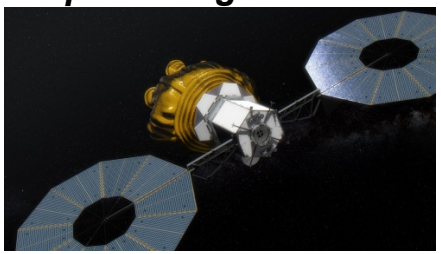
Capture System Deploy



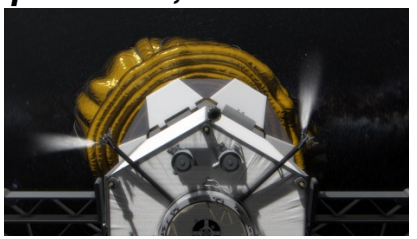
Mechanical Capture



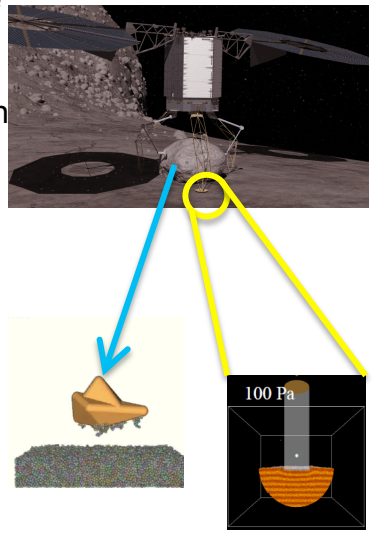
Capture Bag Retraction



Spin down, and Detumble



Robotic Boulder Capture Option



- A second concept for the Asteroid Redirect Robotic Mission (ARRM) would utilize autonomous robotic systems, to capture and firmly restrain a cohesive boulder-like mass (1-5 m diameter) from the surface of a larger asteroid. The system may combine sensor inputs, image processing, and other situational awareness information to create the autonomous sequences. The system will require a software system that can evaluate the sensor inputs and determine the proper action for the robot to accomplish the boulder capture. This concept may use robotic manipulators, articulated trusses, or other types of systems (including inflatables) to grasp and capture the boulder. Although the boulder will be characterized prior to capture operations, its precise friability will likely be unknown until the capture process is underway. The asteroid material needs to be accessible by EVA.

- NASA is particularly interested in, but not limited to:
  - Autonomous capture systems
  - Effectors and grippers
  - Supporting sensors (e.g., ground-penetrating radar)
  - Approaches for determining the mechanical strength of the boulder prior to capture
  - Simple, low-cost regolith and contingency sample collection concepts

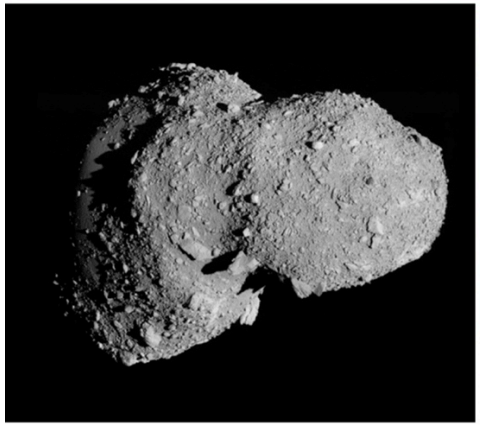
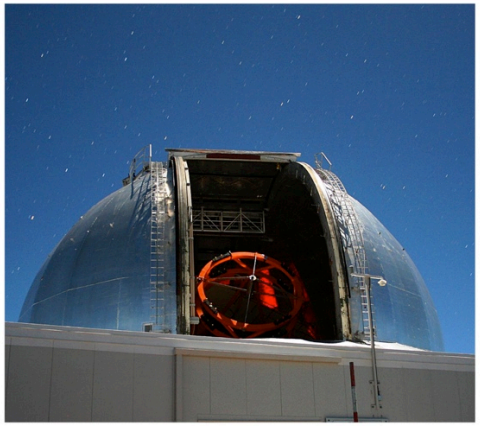
- Systems for acquiring a boulder from a large NEA shall be capable of capturing and controlling a boulder with the following characteristics:
  - Boulder size: 1-5 meter extent in any dimension with capture systems scalable to larger boulders (up to 10 meters) also of interest; aspect ratio < 3:2:1.
  - Boulder mass: typically up to 30 metric tons, but up to 1,000 metric tons for 10 meter size.
  - Boulder assumed to be coherent with compressive strength of at least 0.3 MPa (corresponding to lowest expected strength of carbonaceous chondrite).
  - Parent asteroid rotation rate: up to 0.33 revolutions per hour about any axis or all axes, with up to 1 revolution per hour also of interest.

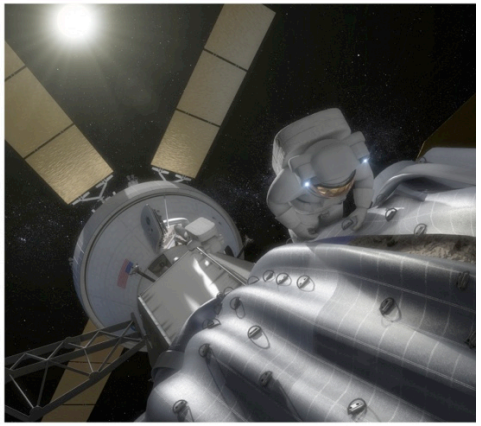
- The proposals shall provide a detailed technical approach for the design, analysis, fabrication, and laboratory testing of a proof-of-concept, subscale capture system. NASA may use the data resulting from this effort in the ARM Mission Concept Review (MCR), which is planned for late 2014 or early 2015.

National Aeronautics and Space Administration

Rendezvous Sensors

Heather Hinkel, JSC



Rendezvous Sensors Needs

- **NASA needs automated rendezvous and docking/capture (AR&D) sensors for both the robotic and crewed segments of the Asteroid Redirect Mission**

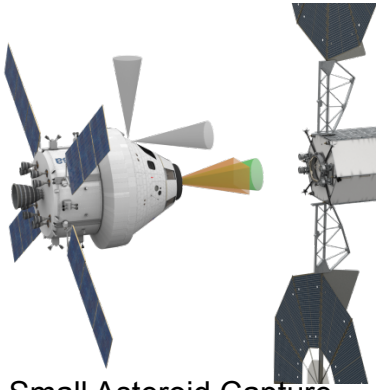
- **NASA is pursuing a common suite of AR&D sensors to apply across all asteroid missions**
  - Visible cameras
    - Medium resolution paired with selectable lenses per mission needs
    - High resolution paired with selectable lenses per mission needs
  - 3D LIDAR
  - Infrared camera

- **Offerors may submit for a single sensor or multiple sensors including the whole suite**

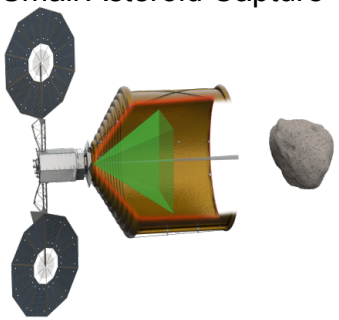
- **NASA created a common specification for environment and performance for each sensor which will fulfill each mission's AR&D needs**

AR&D Concept of Operations

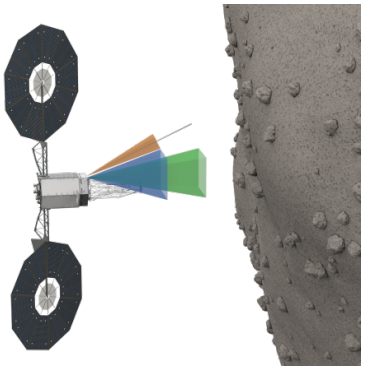
Crewed Asteroid Mission



Small Asteroid Capture



Robotic Boulder Capture



Long Range	Medium Range	Close Range	Application of Common Suite
S-Band Transponder for Range/Range Rate to reduce timeline; Star Tracker for bearing High Resolution Camera for bearing		3D LIDAR for precise alignment for docking High Resolution Camera for secondary pose	High Resolution Camera 3D LIDAR
Medium Resolution Camera for asteroid acquisition, spin rate and bearing to the asteroid		3D LIDAR for asteroid characterization and alignment for bag capture	Medium Resolution Camera 3D LIDAR
Medium Resolution Camera for bearing to the asteroid	Medium and High Resolution Cameras for spin rate, 3D map of the surface and boulder identification	3D LIDAR for 3D range images to the target boulder Medium and High Resolution Cameras for spacecraft pose and images of boulder collection areas	High Resolution Camera Medium Resolution Camera 3D LIDAR

* Addition of infrared camera on asteroid missions for robustness is being assessed

Rendezvous Sensors Appendix Summary

- **NASA intends to fund selected sensor vendors to upgrade their current visible and infrared cameras and 3D LIDAR sensors to satisfy a common specification in the areas of:**
  - Design
  - Risk reduction
  - Technology maturation

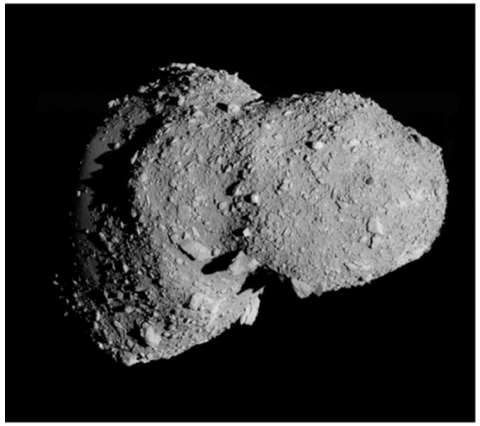
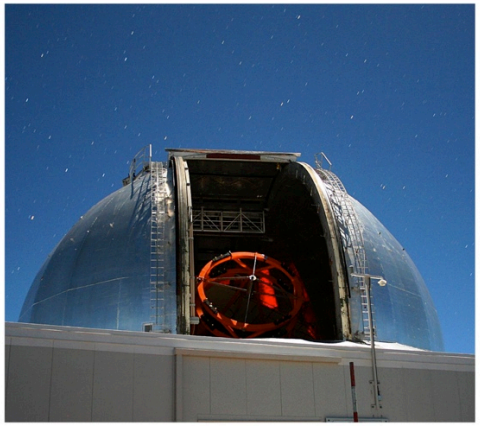
- **Appendix B summary:**
  - Concepts of operations for the three missions
  - Common specification tables: environmental and performance per sensor
  - Request for ideas for incremental suite upgrades
  - Information on requested content of proposals

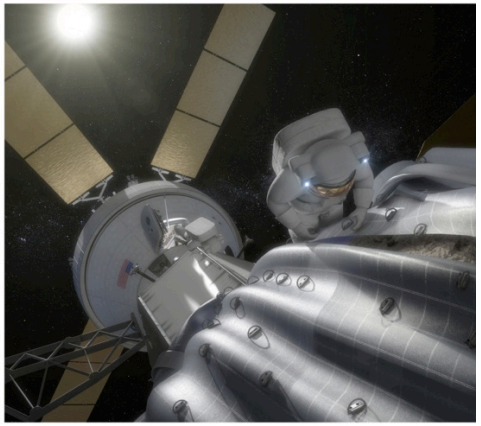
- **Eligible Participants:**
  - This solicitation topic is open to non-government U.S. institutions only (companies, universities, non-profit organizations), and foreign institutions. NASA civil servants and JPL employees may not propose to this solicitation topic.

National Aeronautics and Space Administration

Adapting Commercial Spacecraft for the Asteroid Redirect Vehicle

Mike Barrett, GRC



Adapting Commercial Spacecraft for the Asteroid Redirect Vehicle

- **Objectives:**
  - Conduct industry-led studies of how existing commercial capabilities could be used to reduce the development cost of either the ARV solar electric propulsion module, the mission module, or a combined propulsion and mission module.
  - NASA is particularly interested in developing a standalone high-power SEP tug with an initial capability of approximately 40 kW that could not only permit direct application as a component of the ARV, but also extend to other compelling government and commercial mission applications.

- **Eligible Participants:**
  - This solicitation topic is open to U.S. commercial organizations only. NASA civil servants and JPL employees may not propose to this solicitation topic.

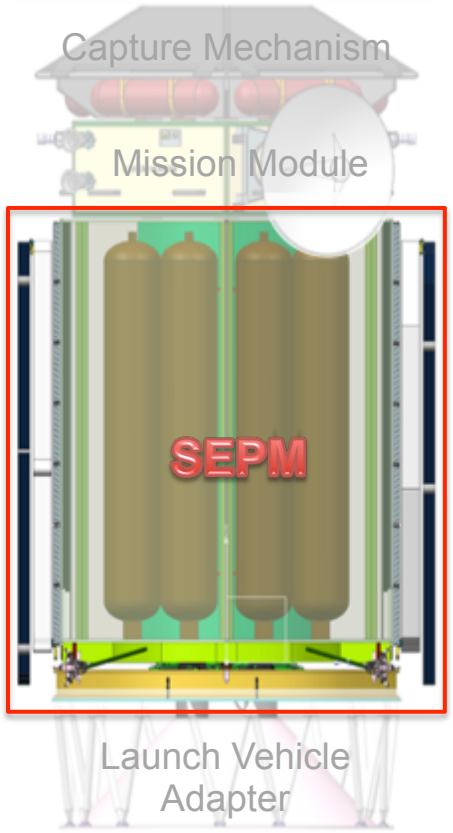
Additional Asteroid Redirect Vehicle Considerations

The ARV is currently being planned with the following considerations:

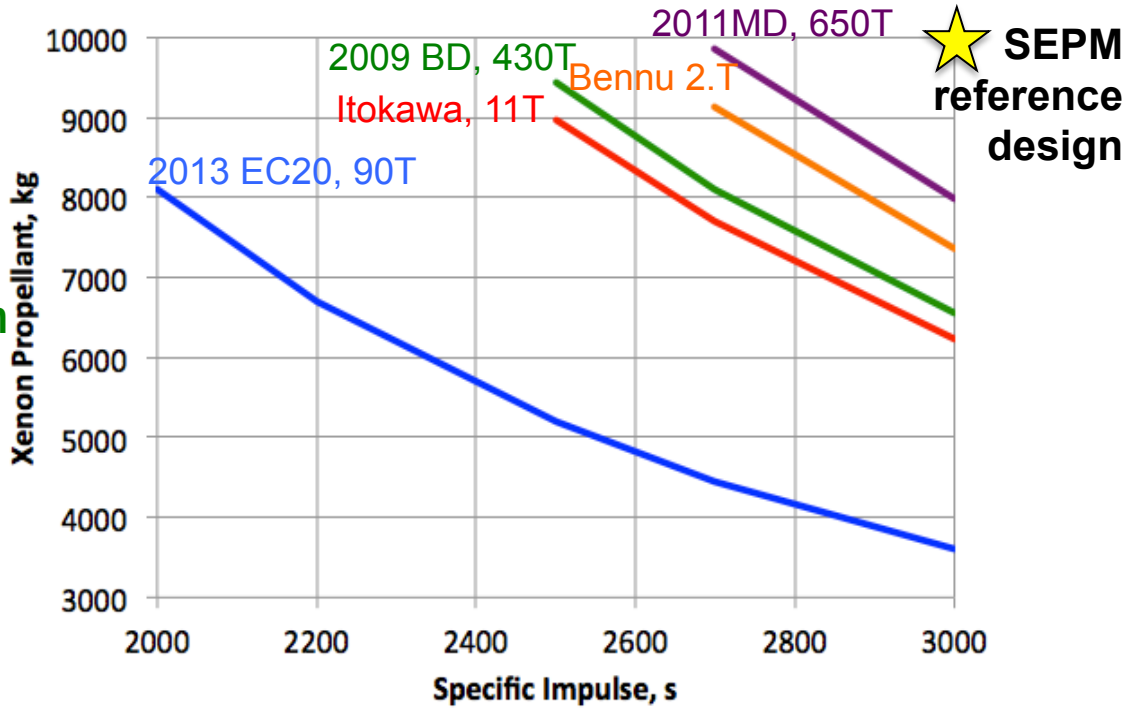
- **Capable of being launched on a single launch vehicle, including Atlas V, Delta IVH, Falcon Heavy, or SLS**
- **Solar electric propulsion system input power approximately 40 kW**
- **Thruster specific impulse between 2,000 and 3,000 seconds**
- **Capable of operating over the range of 0.7 AU to 1.7 AU, including temperature control and communications**
- **System capable of carrying 2,000 to 10,000 kg of xenon**
- **An operational lifetime of at least 6 years in deep space, including radiation tolerance**
- **System must be demonstrated as highly reliable, including appropriately redundant critical systems and operability through fault conditions that include proximity operations with a potentially hazardous non-cooperating body**

SEP Module – Reference Configuration

- **SEPM** is **modular element** of the Asteroid Redirect Vehicle(ARV) defined by the ARRM concept team
- SEPM design based on **max capability** with respect to new technology to offset risk of target selection



- **Solar Array**
- **EP Subsystem**
- **Xe Storage**
- PMAD
- TCS
- RCS
- Mechanical Subsystem

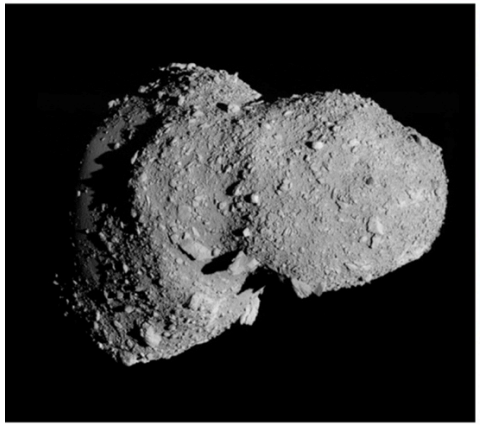
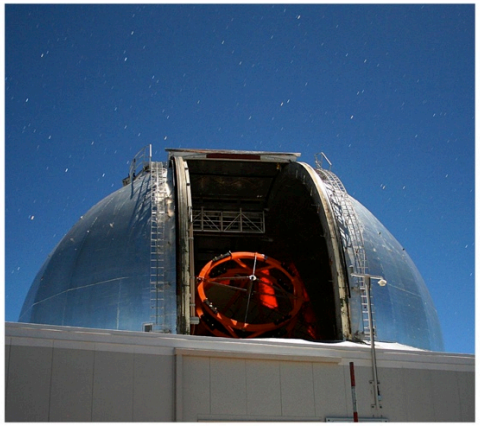


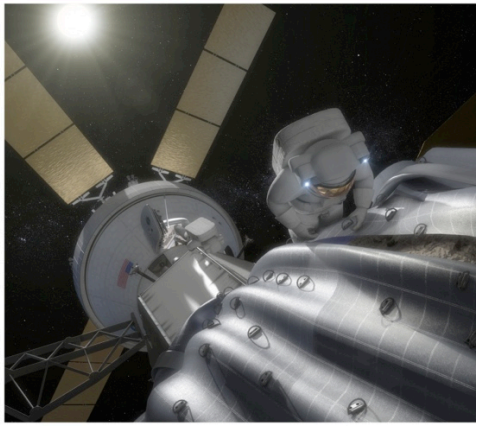
Capability-based SEPM provides broadest mission opportunity for early design study

National Aeronautics and Space Administration

Studies of Potential Future Partnerships for Secondary Payloads

Andy Petro, NASA HQ



Studies of Potential Future Partnership Opportunities for Secondary Payloads – Appendix D

Objective:

Study potential future commercial and international partnership opportunities for launch of secondary payloads

Payloads may address:

- Commercial interests such as asteroid resource prospecting
- Demonstration of planetary defense capabilities
- Strategic Knowledge Gaps (SKGs) for future human exploration

Potential missions:

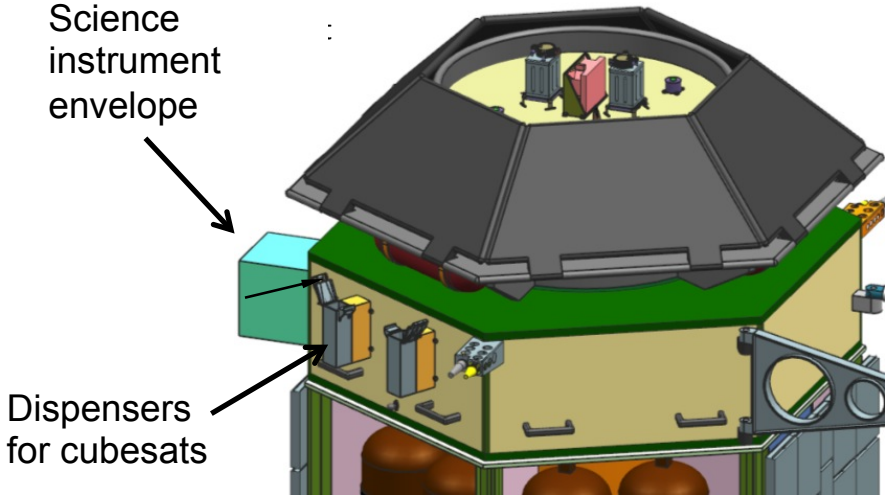
- Ride-along missions on the ARV
- Precursors to potential target asteroids or moons of Mars
- Independent missions for commercial or planetary defense

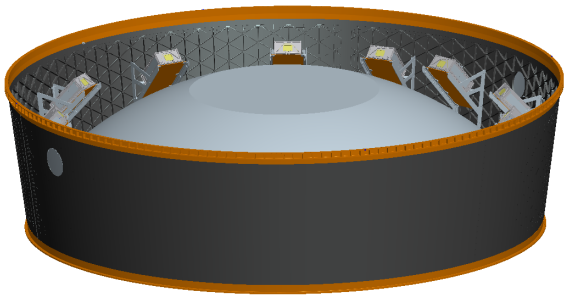
Strategic Knowledge Gaps represent the unknown environments or availability of resources at potential destinations that could impact the design of human spaceflight systems.

Studies of Potential Future Partnership Opportunities for Secondary Payloads – Appendix D

Types of secondary payloads:

- Science instrument on the ARM vehicle mission module
  - up to 50 x 50 x 50 cm, 10 kg, 100 W
- Spacecraft deployed from the ARM vehicle or launched separately
- Cubesat payloads deployed from the ARM
  - up to 6U equivalent, 13 kg (1U = 10 x 10 x 10 cm)
- Cubesat-class payloads deployed from SLS or other launch vehicles
- Kinetic impactors launched with ARV or separately
- Low-cost regolith and contingency sample collection concepts





Example of cubesat payload accommodation on SLS

Studies of Potential Future Partnership Opportunities for Secondary Payloads – Appendix D

Awards:

- Preliminary feasibility studies based on selected proposals will be funded under this BAA.
- Any future partnership agreement will be selected under a separate solicitation
- No funding will be provided for development of payloads.
- For selected partnerships, NASA will provide payload integration, launch, and mission operations support at no cost to the partner.

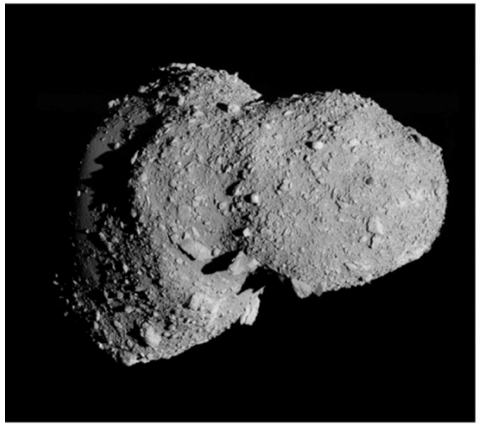
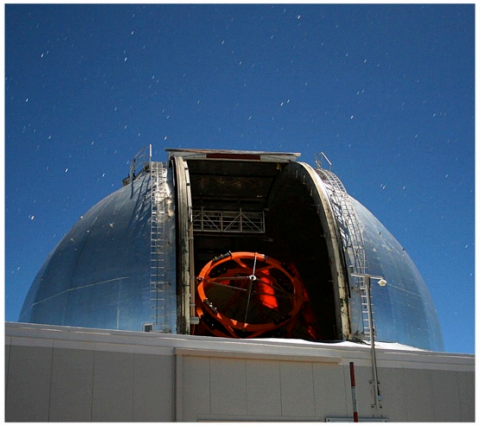
Eligible Participants:

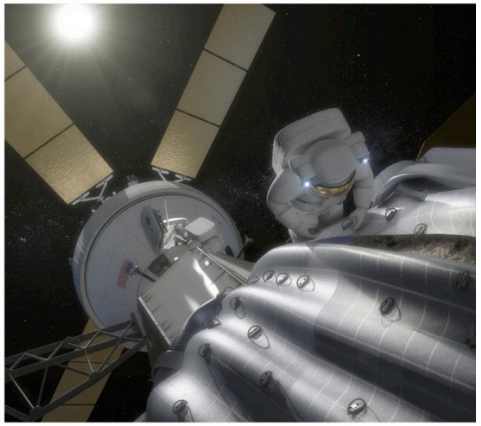
This solicitation topic is open to non-Government U.S. institutions (companies, universities, non-profit organizations) and foreign institutions. NASA civil servants and JPL employees may not propose to this solicitation topic.

National Aeronautics and Space Administration

Studies of Potential Future Partnerships for the Asteroid Redirect Crewed Mission

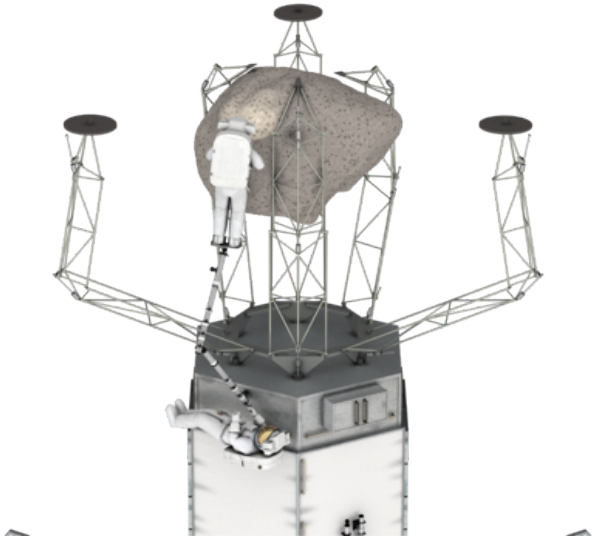
Mark McDonald, JSC

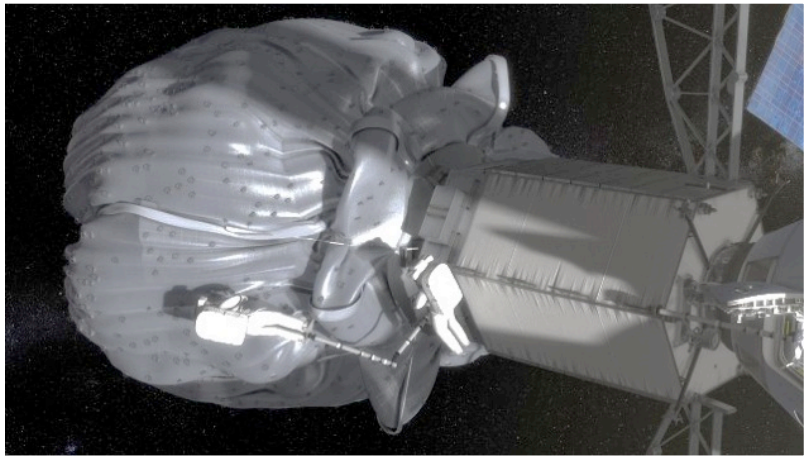





Studies of Crewed Mission Potential Future Partnership Opportunities

- **NASA is interested in studying concepts for potential future partnerships for crewed mission to further utilize the asteroid and enhance extensibility beyond the first mission to the asteroid.**
  - Potential partnerships may include both technical concepts and innovative business models.
  - Focus on secondary mission objectives of science, advancing in-situ resource utilization (ISRU), and enabling commercial activities.
  - Additional interest in partnerships that augment extensibility of the initial crewed mission to support future exploration objectives.





Studies of Crewed Mission Potential Future Partnership Opportunities

Crewed Mission Design Considerations

- **Initial ARCM is extremely mass constrained**
  - Additional payload mass must either be carried on the ARV or launched separately and brought to the ARV in the Lunar Distant Retrograde Orbit (LDRO)
- **Extensibility concepts can enable augmented LDRO activities and/or possibly enable other future exploration missions.**
  - Extensibility concepts should consider additional consumables, functionality and volume required for longer duration crew missions.

Eligible Participants:

This solicitation topic is open to non-Government U.S. institutions (companies, universities, non-profit organizations) and foreign institutions. NASA civil servants and JPL employees may not propose to this solicitation topic.

Future Partnerships:

- Preliminary feasibility studies will be funded under this BAA.
- Any future partnership agreement will be selected under a separate solicitation
- No funding will be provided for development of crewed mission payloads.
- NASA may provide engineering expertise, test facilities, payload integration, launch, mission operations support, and other services at no cost to the partner.

Submitted Questions

1. **Q**: Can an organization submit more than one study proposal?
   A: Yes.

2. **Q:** Can an organization be awarded a study in more than one of the BAA topic areas?
   A: Yes.

3. **Q:** Will each proposal be expected to address only one of the BAA topic areas?
   A: Yes, because the eligibility requirements and maximum funding amounts are different for each topic area.

4. **Q:** Can an organization partner with a NASA Center or JPL on a proposal?
   A: No. NASA civil servants or JPL employees are not eligible to participate in proposals. The main objective of the BAA is to involve the external community in the Asteroid Redirect Mission. NASA Centers and JPL will be funded internally.

5. **Q:** Can Federally Funded Research and Development Centers (FFRDCs) submit proposals?
   A: No. The BAA will be amended to clarify this restriction.